December 22–23, 1922, and January 16–17, 1923, all of which dates lie within the period when the method for obtaining pressures at 1 and 2 kilometers was being tested by daily post card reporting.

The reduced pressures for these high levels in general distribute themselves smoothly, so that they are comparable in this respect with the charts for 1 and 2 kilometers. It is not doubted that the accumulation of data will render future revision of the constants desirable, but this is a matter which does not affect the validity of the method. Granting that slightly more smoothing is required for these charts than is practiced upon the sea level map, there is no mistaking the general trend of horizontal pressure gradients which are the significant and important factors in the determination of the movement of air masses. Isobaric irregularities at these high levels, are, it is believed, less significant than irregularities of the same magnitude on the sea level map.

It has been pointed out before that tests of these maps are very difficult, for one is never sure whether the records of pilot balloon flights are truly representative of air movement at the levels in question. This is not because of inherent inaccuracies in the methods of observing and reduction, but more probably because of the fickleness of wind conditions combined with the fact that the balloon record represents only a momentary observation at any particular level. We know that if the air is in adjustment with the pressure gradient in the free air, it will move nearly parallel to the isobars and with a velocity inversely proportional to the distance between isobars. When the wind direction is not parallel to the isobars, it does not necessarily condemn the isobars, for it may be that the air is not in perfect adjustment to the gradient, or that there are local deviations in the gradient which are so small as to escape record on the map. Local convective influences may greatly disturb the wind direction, yet be extremely local. Therefore, a lack of perfect agreement is not completely attributable to faulty isobars.

On the other hand, there is no desire to utilize this fact as an alibi. The investigator is as curious as the reader to know the true nature of the cause of such discrepancies as may exist; but it is doubtful whether one will ever be able definitely to establish an unimpeachable standard of isobaric accuracy in the free air, owing to the difficulty of simultaneous accessibility of a sufficiently large number of points. One must, in all fairness, judge the results of this map drawing in a broad way and attempt to compare large movements of air as indicated by simultaneous free-air wind directions at aerological stations with general isobaric trend. It is asking too much at this, and probably at any, stage of free-air map drawing to expect every wind direction to agree with the isobaric trend in its immediate vicinity. This does not always hold even at the surface close to the reduction level, although in that case we have recourse to turbulence, friction, and topography to explain the discrepancy; and such explanations can not be drawn upon in such large measure in the free air.

With these introductory remarks, Figure 7, showing the pressures at sea level, 2, 3, and 4 kilometers for December 22–23, 1923, and January 16–17, 1922, respectively, may be studied. On these charts are plotted the wind directions observed by means of pilot balloons at or near 8 a. m., 75th meridian time. These dates were selected because of the large number of ascents reaching the required altitudes. The speed of the wind in miles per hour is indicated by the barbs on the arrows, one barb indicating 10 miles of wind per hour.

These charts are offered in the hope that the reader will study them and draw his own conclusions as to the agreement between wind direction and isobaric trend, and the relation between the barometric configurations at the several levels. It is recognized that the number of maps is small, but available time and space hardly justify the presentation of more. No attempt is made to discuss the physical relations between wind conditions at the several levels, since the object of this paper is to treat only of the method of reduction and its application to map drawing. It will be conceded, it is hoped, that the Law of Pressure Ratios is one of theoretical interest and considerable practical importance. It has the merit of being founded on firm theoretical grounds and confirmed by observation so closely that the final error of computation is largely a function of the pressure errors at 1 and 2 kilometers above sea level—and these have been shown to be satisfactorily small.

ACKNOWLEDGMENTS.

The author wishes to thank Mr. E. W. Woolard, for his courtesy and helpfulness in discussing and verifying the equations employed, and members of the Aerological Division of the Weather Bureau for their very willing and enthusiastic assistance at every point where collaboration was requested.

## THE WINDS OF OKLAHOMA AND EAST TEXAS.

By JOHN A. RILEY, Meteorologist.

[Aerological Station, Broken Arrow, Okla., September 26, 1923.]

SYNOPSIS.

Some of the outstanding features of surface and free-air winds over Oklahoma and east Teaxs are presented in tables and graphs. The data are mainly based on four years' pilot balloon records at three stations: Broken Arrow and Fort Sill, Okla., and Groesbeck, Tex., with a total of 7,075 flights. The paper does not aim at completeness for all phases of the wind even for the region covered; an exhaustive compilation of the data for this and other geographic groups is to be published later by the Aerological Division as Part II of *An Aerological Survey of the United States*.

Notable features of the winds of this group are: At the surface, largely predominating south winds in summer and alternate north and south winds in winter, with a small percentage of east and west winds in all seasons. In the free air, a clockwise shift, with one exception, into a pronounced westerly drift aloft in all seasons; a north component amounting to more than 50 per cent at 4,000 meters and higher over the whole region in all seasons. The one exception is the summer winds of Texas in which a counterclockwise shift occurs, the wind having a northeasterly drift above 4,000 meters.

Graphs have been drawn to show the mean seasonal direction and velocity at the three stations; the percentage frequency of directions for summer, winter, and the year at four selected levels; the annual march of wind speeds based on monthly averages for the region as a whole; features of the diurnal march and the nocturnal stratification of speeds at low altitudes; and the frequency of high winds at ordinary flying levels.

Free-air winds are best studied in geographic groups such that conditions are nearly uniform throughout the group but differ in some particulars from conditions in other groups. Upper air conditions at various levels are also more uniformly distributed than are those at the surface, so that the network of aerological stations need not be so close to arrive at an idea of averages as is necessary for surface stations which are frequently affected by local topography and the exposure of the station.

The region embraced in this study—Oklahoma and east Texas—is represented by three stations: Broken Arrow in northeastern Oklahoma and Fort Sill in the southwestern part of the State, and Groesbeck in east central Texas. Pilot balloon work is carried on at all three stations; kite work is done at the two Weather Bureau stations but not at Fort Sill. The data may be said to represent fairly well the territory from latitude 31° to 37° north and from longitude 95° to 99° west.

Most of this region is in the once famous grass country of the Southwest; it is now an agricultural and industrial district of importance. Except for the rugged and forested mountains of eastern and south-central Oklahoma which rise in some instances to 2,500 or 3,000 feet above sea level, the surface is in general a vast rolling plain. From the lofty plateau of 2,000 feet above sea level in the western part there is a gentle slope toward the south and east to less than 500 feet in the southeast.

The three stations are located in open country, freely exposed to winds from all directions, so that the records at lower levels are not affected by unusual topography. The geographical coordinates and elevation of each station and the record used in this study are given in Table 1.

TABLE 1.

| Station. | Altitude, m. s. l. | Latitude, N. | | Longitude, W. | | Period of observations (inclusive). | |
|---|---|---|---|---|---|---|---|
| | *Meters.* | ° | ′ | ° | ′ | From— | To— |
| Broken Arrow, Okla.. | 233 | 36 | 02 | 95 | 49 | November, 1918... | October, 1922. |
| Fort Sill, Okla....... | 355 | 34 | 40 | 98 | 25 | July, 1918......... | June, 1922. |
| Groesbeck, Tex...... | 141 | 31 | 30 | 96 | 28 | November, 1918... | October, 1922. |

Four years' pilot balloon records for each station have been used in preparing the tables of mean values. The balloons are released at 7 a. m. and 3 p. m., near the time of the extremes in the diurnal march of the winds, and the combined means therefore represent a close approach to the true daily mean.

Single-theodolite observations are the rule, but at the Weather Bureau stations two-theodolite observations are made as often as time will permit. In the lower levels on summer afternoons the ascensional rate of the balloon is sometimes seriously disturbed by convection; at such times two-theodolite work is necessary for accurate results. Vertical air currents are practically absent in the morning and comparisons of morning kite and balloon records show very satisfactory agreement in the two methods. The errors incident to certain individual observations compensate one another and in the means based on a large number of observations are nearly if not entirely eliminated.

A two-year summary, previously prepared for Broken Arrow and Fort Sill,[1] affords a comparison of the two-year with the present four-year means. The seasonal means for the two periods show very small differences; the annual means are almost identical. At no level is there a greater difference than 4° in direction and 0.7 m. p. s. in velocity in the annual means. Monthly values have not been considered, except in preparing Figure 4, because a longer period of observations is necessary for the determination of normal monthly values.

[1] Mo. WEATHER REV., November, 1920. 48: 627-632.

The number of observations for each season and the year is given in Table 5. The largest number occurs in summer and the least in winter, although the differences are small and the seasonal distribution is entirely satisfactory. The percentage of observations made during the entire period is 87 at Broken Arrow, 72 at Fort Sill, and 83 at Groesbeck. The percentage of days on which at least one observation was made is considerably higher and therefore agrees well with percentage of days on which kite flights are made. With increasing altitude above 3,000 meters the percentage of balloon observations over those made with kites rapidly increases, especially in summer, and at 5,000 meters and higher balloons furnish the only means at present used for observing the winds regularly. At Broken Arrow 43 per cent of all balloon observations reach 4,000 meters; 20 per cent at Fort Sill and 38 per cent at Groesbeck reach this level. Six per cent of all observations at Broken Arrow and Groesbeck reach the 10-kilometer level.

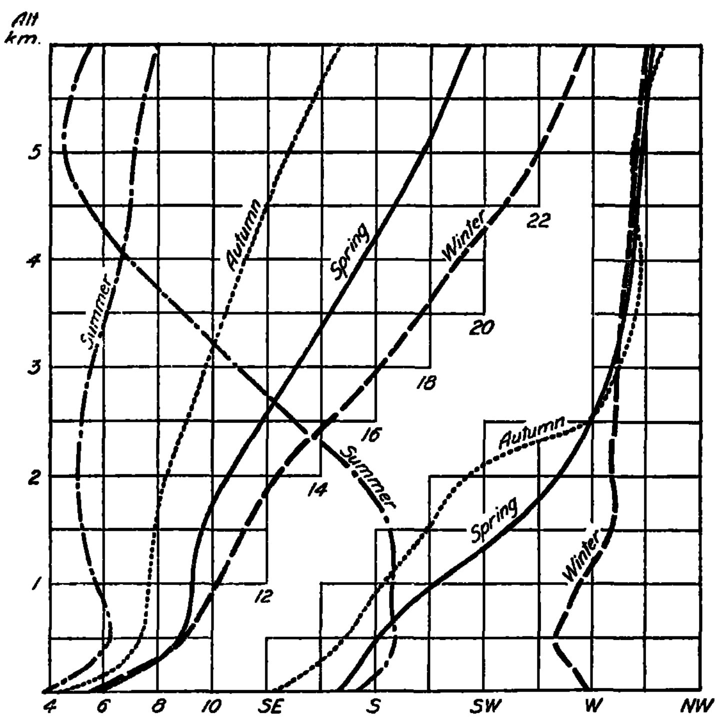


FIG. 1.—Mean seasonal free-air wind directions and velocities (m. p. s.), Broken Arrow Okla.

Disappearances of balloons are due mostly to clouds and secondly to distance. But while lower clouds seriously interfere with the work at times, the data obtained by this method are not limited to fair weather. Observations are often obtained between showers or through temporary breaks in the clouds; in fact they can be made near thunderstorms when it would be dangerous to send up kites. So that nearly all conditions are represented except storm centers where rain and low clouds are general.

Mean velocities, as in other free-air studies of this kind, have been determined by applying to the mean velocities the gradient from each level to the next higher level, thus eliminating the discontinuities resulting from fewer observations at the higher levels. Mean directions are found by resolving each direction into its north and west components and determining the mean trigonometrically. This is different from getting the prevailing direction as recorded at the regular stations, which is the direction occurring the greatest number of times regardless of the distribution and frequency of the other directions. The surface directions in winter, as shown in Figure 5, afford a good example of this difference. Prevailing directions would be either north or south, but when the components of all directions are considered a westerly drift is found.

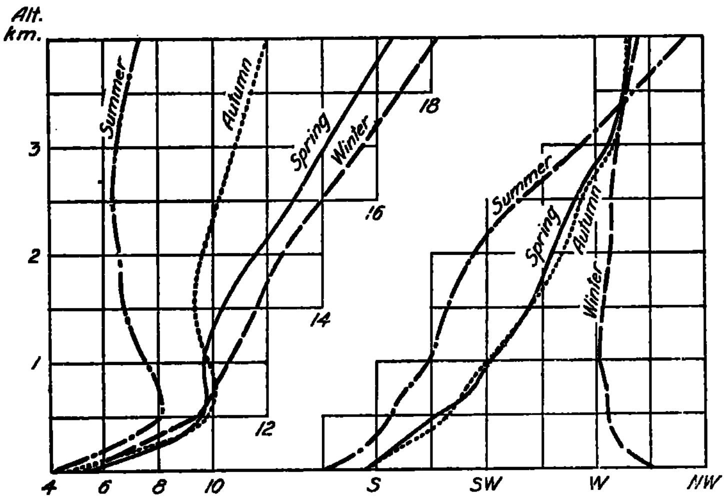


FIG. 2.—Mean seasonal free-air wind directions and velocities (m. p. s.), Fort Sill, Okla.

## AVERAGE WINDS.

Seasonal means of direction and velocity are shown in Tables 2, 3, and 4, and graphically in Figures 1, 2, and 3. Mean surface velocities range from 4 to 7 m. p. s. In the

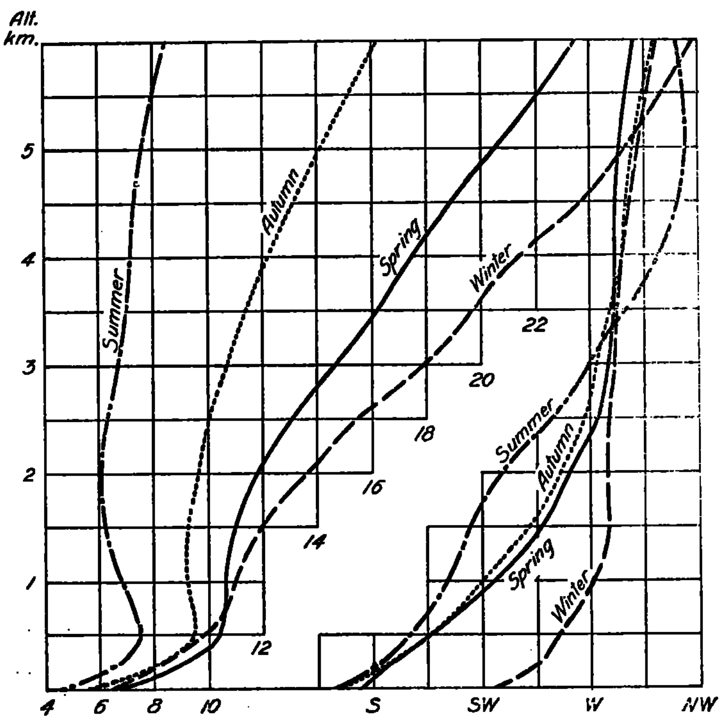


FIG. 3.—Mean seasonal free-air wind directions and velocities (m. p. s.), Groesbeck, Tex.

free air three regions may be distinguished: (1) A region of rapid increase in velocity to approximately 500 meters; (2) slight increase or even a decrease throughout the next kilometer, varying in amount and depth with the season; and (3) a region of steady increase in velocity. Light winds prevail at all altitudes in summer, the lightest free-air winds occurring at a height of 2,000 meters. Autumn wind speeds of this region, unlike those of more northerly stations, are considerably less than those of spring; an almost uniform increase in speed occurs in the upper levels from summer through autumn, spring, and winter.

TABLE 2.—*Mean free-air winds at Broken Arrow, Okla.*

| Altitude (meters). | Spring. | | Summer. | | Autumn. | | Winter. | | Annual. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). |
| | ° | | ° | | ° | | ° | | ° | |
| Surface | S. 6 E. | 6.6 | S. 16 E. | 4.5 | S. 15 E. | 5.6 | S. 50 W. | 6.3 | S. 7 E. | 5.8 |
| 250 | S. 8 W. | 9.1 | S. 5 W. | 6.8 | S. 8 W. | 8.4 | S. 69 W. | 8.4 | S. 14 W. | 8.2 |
| 500 | S. 22 W. | 10.4 | S. 14 W. | 7.5 | S. 23 W. | 9.5 | S. 76 W. | 9.7 | S. 28 W. | 9.3 |
| 750 | S. 37 W. | 10.6 | S. 23 W. | 7.2 | S. 35 W. | 9.4 | S. 85 W. | 10.5 | S. 41 W. | 9.4 |
| 1,000 | S. 50 W. | 10.6 | S. 31 W. | 6.8 | S. 45 W. | 9.2 | N. 88 W. | 11.0 | S. 51 W. | 9.4 |
| 1,500 | S. 69 W. | 11.0 | S. 41 W. | 6.3 | S. 65 W. | 9.2 | N. 82 W. | 11.9 | S. 68 W. | 9.6 |
| 2,000 | S. 80 W. | 11.8 | S. 53 W. | 6.1 | S. 78 W. | 9.7 | N. 83 W. | 13.6 | S. 79 W. | 10.3 |
| 2,500 | N. 87 W. | 13.1 | S. 75 W. | 6.3 | S. 88 W. | 10.0 | N. 82 W. | 15.4 | W. | 11.2 |
| 3,000 | N. 82 W. | 14.7 | W. | 6.7 | N. 88 W. | 10.7 | N. 80 W. | 17.9 | N. 84 W. | 12.5 |
| 4,000 | N. 79 W. | 17.5 | N. 61 W. | 7.2 | N. 77 W. | 12.2 | N. 77 W. | 21.4 | N. 74 W. | 14.6 |
| 5,000 | N. 78 W. | 20.5 | N. 50 W. | 7.6 | N. 72 W. | 14.1 | N. 69 W. | 25.3 | N. 66 W. | 16.8 |
| 6,000 | N. 71 W. | 23.5 | N. 55 W. | 8.5 | N. 64 W. | 16.2 | N. 62 W. | 27.8 | N. 62 W. | 19.0 |

TABLE 3.—*Mean free-air winds at Fort Sill, Okla.*

| Altitude (meters). | Spring. | | Summer. | | Autumn. | | Winter. | | Annual. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). |
| | ° | | ° | | ° | | ° | | ° | |
| Surface | S. 5 E. | 5.5 | S. 21 E. | 4.1 | S. 5 E. | 4.6 | N. 66 W. | 5.3 | S. 7 E. | 4.9 |
| 250 | S. 10 W. | 8.2 | S. 4 E. | 6.6 | S. 12 W. | 8.1 | N. 81 W. | 7.5 | S. 13 W. | 7.6 |
| 500 | S. 24 W. | 9.6 | S. 5 W. | 8.1 | S. 29 W. | 9.8 | N. 85 W. | 9.4 | S. 28 W. | 9.2 |
| 750 | S. 39 W. | 9.8 | S. 11 W. | 8.0 | S. 35 W. | 10.1 | N. 86 W. | 10.0 | S. 38 W. | 9.5 |
| 1,000 | S. 45 W. | 9.7 | S. 21 W. | 7.6 | S. 45 W. | 9.8 | N. 89 W. | 10.6 | S. 47 W. | 9.4 |
| 1,500 | S. 62 W. | 10.3 | S. 29 W. | 6.8 | S. 62 W. | 9.3 | N. 87 W. | 11.6 | S. 61 W. | 9.5 |
| 2,000 | S. 72 W. | 11.5 | S. 39 W. | 6.6 | S. 77 W. | 9.6 | N. 83 W. | 12.4 | S. 74 W. | 10.0 |
| 2,500 | S. 82 W. | 13.0 | S. 58 W. | 6.3 | S. 84 W. | 10.0 | N. 83 W. | 13.9 | S. 84 W. | 10.8 |
| 3,000 | N. 84 W. | 14.1 | S. 83 W. | 6.5 | N. 82 W. | 10.8 | N. 80 W. | 15.5 | N. 84 W. | 11.7 |
| 4,000 | N. 76 W. | 16.6 | N. 53 W. | 7.4 | N. 77 W. | 12.0 | N. 71 W. | 18.2 | N. 73 W. | 13.5 |

TABLE 4.—*Mean free-air winds at Groesbeck, Tex.*

| Altitude (meters). | Spring. | | Summer. | | Autumn. | | Winter. | | Annual. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). | Direction. | Velocity (m./s.). |
| | ° | | ° | | ° | | ° | | ° | |
| Surface | S. 15 E. | 5.8 | S. 7 E. | 3.8 | S. 43 E. | 4.2 | S. 89 W. | 5.5 | S. 10 E. | 4.8 |
| 250 | S. 6 E. | 7.8 | S. 4 W. | 5.6 | S. 23 E. | 6.7 | S. 82 W. | 7.7 | S. 2 W. | 7.0 |
| 500 | S. 1 W. | 8.9 | S. 8 W. | 6.3 | S. 11 E. | 7.4 | S. 76 W. | 9.0 | S. 10 W. | 7.9 |
| 750 | S. 11 W. | 9.1 | S. 5 W. | 6.1 | S. 5 E. | 7.6 | S. 80 W. | 9.6 | S. 15 W. | 8.1 |
| 1,000 | S. 24 W. | 9.3 | S. 6 W. | 5.7 | S. 3 W. | 7.7 | S. 85 W. | 10.1 | S. 24 W. | 8.2 |
| 1,500 | S. 56 W. | 9.6 | S. 6 W. | 5.3 | S. 21 W. | 7.9 | N. 82 W. | 11.2 | S. 46 W. | 8.5 |
| 2,000 | S. 78 W. | 10.6 | S. 7 E. | 5.0 | S. 37 W. | 8.3 | N. 83 W. | 12.4 | S. 65 W. | 9.1 |
| 2,500 | S. 89 W. | 11.7 | S. 34 E. | 5.2 | S. 89 W. | 9.1 | N. 81 W. | 14.2 | S. 84 W. | 10.0 |
| 3,000 | N. 82 W. | 13.1 | S. 57 E. | 5.5 | N. 79 W. | 9.8 | N. 81 W. | 16.2 | N. 86 W. | 11.2 |
| 4,000 | N. 74 W. | 15.5 | N. 79 E. | 6.6 | N. 69 W. | 11.2 | N. 75 W. | 19.1 | N. 68 W. | 13.1 |
| 5,000 | N. 69 W. | 17.8 | N. 51 E. | 7.1 | N. 74 W. | 12.8 | N. 71 W. | 22.0 | N. 60 W. | 15.0 |
| 6,000 | N. 65 W. | 19.4 | N. 62 E. | 8.0 | N. 60 W. | 14.7 | N. 68 W. | 23.7 | N. 51 W. | 16.4 |

TABLE 5.—*Number of observations on which Tables 2, 3, and 4 are based.*

| Altitude (meters). | Broken Arrow, Okla. | | | | | Fort Sill, Okla. | | | | | Groesbeck, Tex. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring. | Summer. | Autumn. | Winter. | Annual. | Spring. | Summer. | Autumn. | Winter. | Annual. | Spring. | Summer. | Autumn. | Winter. | Annual. |
| Surface | 642 | 694 | 631 | 572 | 2,539 | 549 | 550 | 527 | 483 | 2,109 | 613 | 635 | 626 | 553 | 2,427 |
| 250 | 642 | 694 | 625 | 571 | 2,532 | 549 | 549 | 527 | 482 | 2,107 | 611 | 633 | 619 | 551 | 2,414 |
| 500 | 629 | 688 | 613 | 551 | 2,481 | 532 | 544 | 515 | 473 | 2,064 | 578 | 603 | 594 | 509 | 2,284 |
| 750 | 598 | 672 | 590 | 529 | 2,389 | 508 | 533 | 490 | 448 | 1,979 | 525 | 577 | 570 | 460 | 2,132 |
| 1,000 | 561 | 663 | 581 | 508 | 2,313 | 470 | 519 | 471 | 424 | 1,884 | 489 | 555 | 540 | 430 | 2,014 |
| 1,500 | 486 | 634 | 538 | 470 | 2,128 | 393 | 473 | 386 | 376 | 1,628 | 415 | 511 | 476 | 364 | 1,766 |
| 2,000 | 423 | 587 | 494 | 419 | 1,923 | 299 | 372 | 309 | 299 | 1,279 | 355 | 454 | 431 | 321 | 1,561 |
| 2,500 | 344 | 524 | 434 | 369 | 1,671 | 210 | 209 | 225 | 223 | 933 | 299 | 411 | 381 | 271 | 1,362 |
| 3,000 | 291 | 487 | 394 | 330 | 1,502 | 151 | 203 | 167 | 165 | 686 | 251 | 385 | 341 | 238 | 1,215 |
| 4,000 | 202 | 375 | 290 | 215 | 1,082 | 91 | 128 | 103 | 92 | 414 | 177 | 309 | 271 | 164 | 921 |
| 5,000 | 122 | 292 | 230 | 128 | 772 | .... | .... | .... | .... | ...... | 130 | 240 | 213 | 112 | 695 |
| 6,000 | 83 | 227 | 174 | 80 | 564 | .... | .... | .... | .... | ...... | 97 | 180 | 166 | 74 | 517 |

Spring and autumn direction curves are much alike except at Groesbeck where the south component is much deeper in autumn than in spring; from south or southeast at the surface the wind veers to west at 3,000 meters with little change thereafter. Winter directions average nearly west at all altitudes. Summer directions show the deepest south components and the most rapid shift in the mean direction to farthest north in the upper levels. At Broken Arrow and Fort Sill there is a clockwise shift in summer from southwest at 2,000 meters to northwest at 4,000 meters and higher levels; at Groesbeck a counterclockwise shift sets in at 1,500 meters, the wind backing from south through east at 3,700 meters to northeast at 5,000 meters. There is therefore a marked northerly drift at high altitudes over the whole region in summer, with a westerly component prevailing over Oklahoma and an easterly one over Texas.

The strong east component in the upper levels above Groesbeck in summer continuing, as will be seen later, to 10 kilometers should be of interest in connection with the observed movements of upper clouds. It is in decided contrast to conditions farther north, where cirrus clouds are rarely observed moving from the east, to find that at least in Texas in summer cirrus are likely to move from the east more frequently than from the west.

During winter this region is dominated by the prevailing westerlies and average velocities are nearly as strong as those at stations farther north; this is in agreement with the charts of free-air isobars determined from kite observations.[2] In summer the southern part is invaded by the "horse latitudes." But this subtropical control is limited to the free air as shown by the large percentage of weak easterly winds. At the surface and at lower levels the wind blows steadily from the south at all places; this circulation has a monsoon character as explained by Tannehill,[3] caused by the high temperatures of the interior.

Statistical data from other southern stations are necessary to determine more completely the free-air winds of this subtropical region and reports from regions outside the United States are needed to show the effect of the southwestern continental "heat island" on the upper planetary winds.

Figure 4 gives in another way the annual distribution of velocities. It is based on the combined monthly values of the three stations thus giving a composite picture of the annual march of velocities over the region as a whole. The marked contrast in the strength of summer and winter winds is emphasized in this diagram. It will be observed that strong winds persist from late November to early April. A sudden decrease sets in at all levels in late April and early May; in the upper levels the decrease continues through May and June. During July and August stagnant conditions prevail to great heights and the average speed from 1,500 meters to 3,000 meters falls below 6 m. p. s. Increasing velocities set in again during September and by late November have reached winter force at all altitudes.

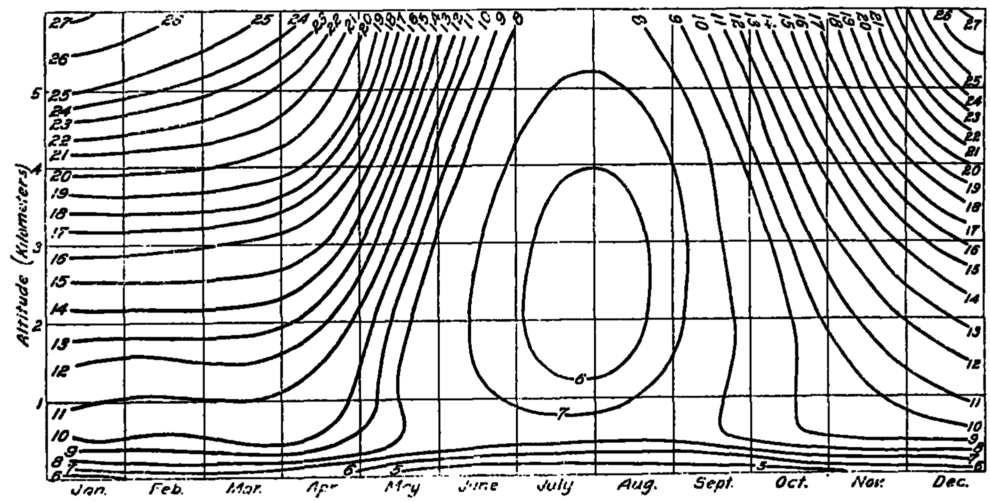


FIG. 4.—Annual distribution of velocities (m. p. s.), based on combined monthly means of three stations.

*Frequency of winds from different directions.*—Figure 5 gives the percentage frequency of directions at the surface and at 1, 3, and 4 kilometers elevation. The directions for the three stations have been plotted on outline maps of Oklahoma and Texas and show the distribution to 16 points for summer (June, July, and August), winter (December, January, and February), and the year. The surface distribution is notable for the preponderance of north and south winds over east and west winds at all seasons, and of south component winds in summer. For the year winds falling within one point of either north or south constitute 62 per cent of the total at Broken Arrow, 68 per cent at Fort Sill, and 54 per cent at Groesbeck. During summer the percentage of winds within one point of south is 52 at Broken Arrow, 49 at Fort Sill, and 42 at Groesbeck. During winter there is nearly a balance between the north and south winds.

At 1,000 meters many of the directly north and south surface winds have shifted a point or two toward west; and the greatest frequency is in the southwest quadrant. At 3,000 meters and 4,000 meters winter winds are nearly all from points between southwest and northwest. Summer winds are more evenly distributed from all directions, with a prevailing westerly component at the two Oklahoma stations and an easterly component at Groesbeck.

*West component.*—Table 6 gives the percentage frequency of a west component and a north component for the summer and winter seasons and the year. A west component occurs in winter generally 90 per cent or more of the time above 2,000 meters. In summer there is a marked decrease in the proportion of west

[2] *An aerological survey of the United States.* By W. R. Gregg. MO. WEATHER REVIEW, SUPPLEMENT NO. 20.

[3] *Some characteristics of Texas rainfall.* By I. R. Tannehill. MO. WEATHER REV. May 1923. See also, *Cause of the accelerated sea-breeze over Corpus Christi, Tex.* By J. P. McAuliffe, MO. WEATHER REV., November, 1922.

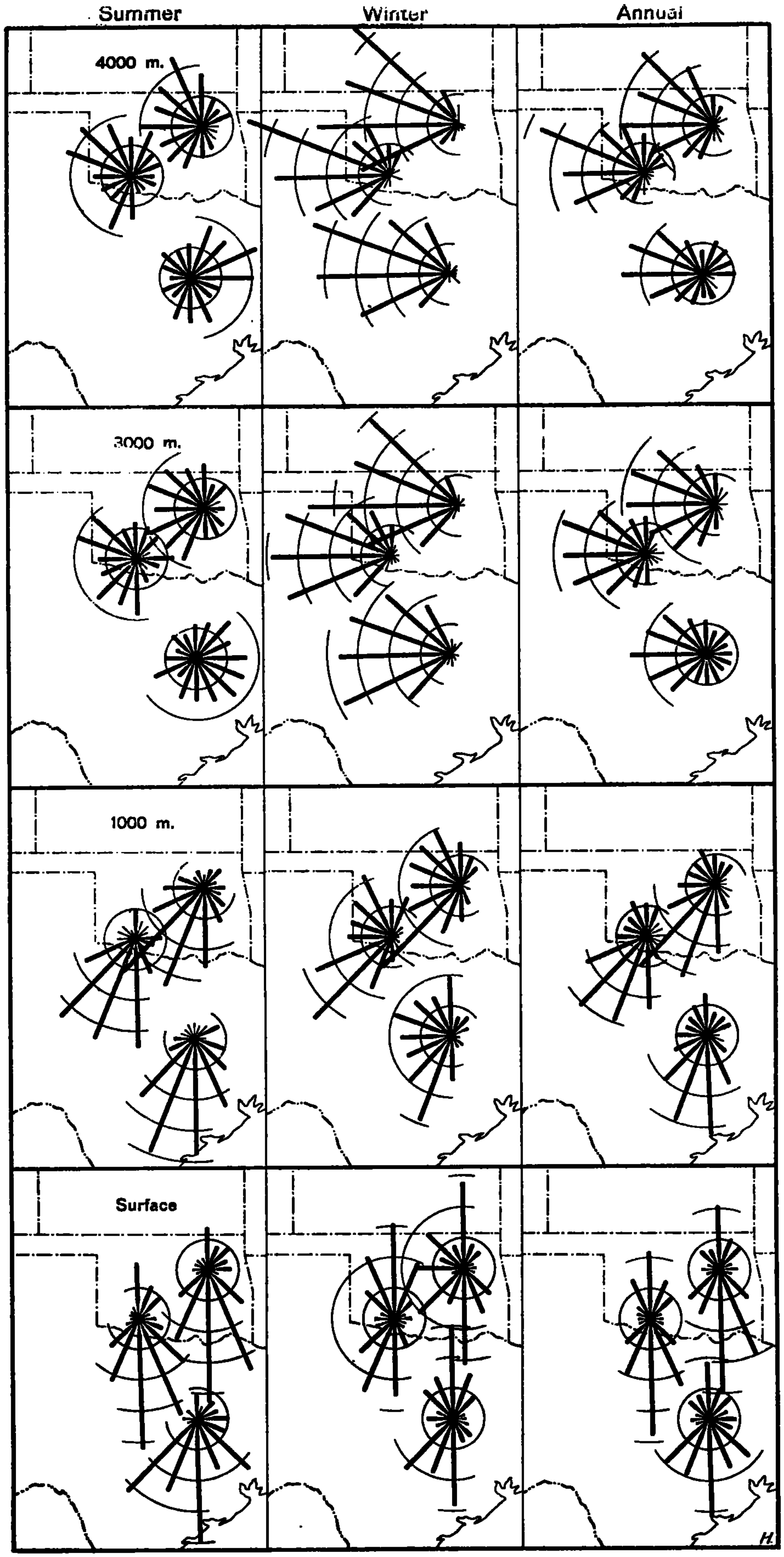


FIG. 5.—Percentage frequency of winds from different directions.

component winds with decreasing latitude, and at southern stations a steady decline of these winds with increasing altitude. At Broken Arrow in summer the percentage of west component winds is close to 70 from 1 to 6 kilometers, while at Groesbeck the percentage falls from 56 at 1 kilometer to 34 at 6 kilometers.

TABLE 6.—*Percentage frequency of a west and a north component.*

| | West component. | | | | | | | North component. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Altitude (kilometers). | | | | | | | | | | | | | |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **BROKEN ARROW.** | | | | | | | | | | | | | | |
| | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* |
| Summer | 40 | 67 | 68 | 68 | 67 | 71 | 70 | 28 | 25 | 37 | 51 | 58 | 66 | 64 |
| Winter | 56 | 78 | 93 | 95 | 95 | 93 | 93 | 45 | 50 | 54 | 59 | 62 | 72 | 78 |
| Year | 45 | 72 | 79 | 80 | 81 | 80 | 80 | 35 | 35 | 44 | 54 | 59 | 65 | 68 |
| **FORT SILL.** | | | | | | | | | | | | | | |
| Summer | 38 | 63 | 66 | 62 | 61 | ..... | ..... | 27 | 23 | 33 | 50 | 59 | ..... | ..... |
| Winter | 59 | 77 | 89 | 89 | 87 | ..... | ..... | 52 | 48 | 52 | 56 | 62 | ..... | ..... |
| Year | 48 | 70 | 79 | 77 | 76 | ..... | ..... | 39 | 34 | 41 | 53 | 60 | ..... | ..... |
| **GROESBECK.** | | | | | | | | | | | | | | |
| Summer | 47 | 56 | 49 | 42 | 40 | 39 | 34 | 20 | 19 | 34 | 44 | 54 | 59 | 59 |
| Winter | 58 | 75 | 87 | 91 | 90 | 92 | 91 | 49 | 50 | 54 | 56 | 63 | 69 | 70 |
| Year | 47 | 60 | 64 | 65 | 65 | 66 | 64 | 35 | 34 | 44 | 51 | 59 | 61 | 64 |

*North component.*—The slight depth of many north surface winds, especially in summer, is shown by the fact that the north component is generally less at 1,000 meters than at the surface (Table 6); above 1,000 meters the north component increases and passes 50 per cent in all seasons at 3,000 meters over Oklahoma and at 4,000 meters over Texas. The north component is greatest in winter and least in summer.

It is paradoxical that while a north component at 4,000 meters and higher is less frequent in summer than in winter the mean direction is nearer north in summer than in winter. This is explained by the fact that in winter many of the north component winds are from nearly west, i. e., west-northwest, while in summer a larger proportion of these winds are from north and north-northwest, thus bringing the mean direction around farther toward the north.

### THE DIURNAL MARCH.

Diurnal changes in free-air winds as in other meteorological elements are more apparent at southern stations than at northern stations where the diurnal changes are largely obscured by the changes resulting from the more frequent passage of HIGHS and LOWS. The essential characteristics of the diurnal change are: Stronger free-air winds at night, with a pronounced apex in the velocity curve at 500 meters; and at the surface conditions just the reverse, i. e., light winds at night and strong winds in daytime. With the velocity change there also occurs a diurnal change in direction, the surface wind during the day following more closely the direction of the free-air wind at 1,000 meters.

The importance of stratification of free-air winds was brought out during the national balloon race of 1922, when it is said one of the contestants found a layer of strong velocity barely deep enough to reach from the top to the bottom of the balloon.[4] This current was effective in enabling him to win the race. While such pronounced stratification is not often observed at considerable altitudes, or at low altitudes during daytime, there is a nocturnal stratification in this region that occurs with great regularity, and is of such strength as to merit the attention of aviators. It will be particularly important in the case of night flying.

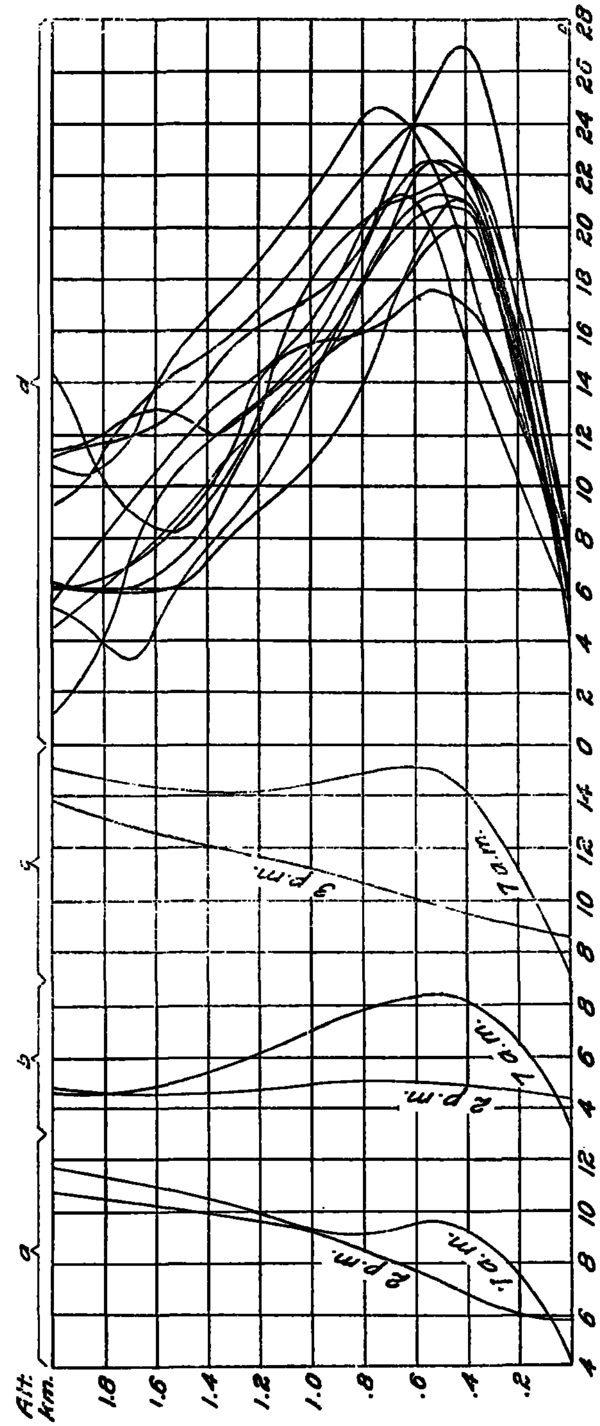


FIG. 6.—(a, b, c) Mean a. m. and p. m. velocity curves: (a) January, and (b) July, at Groesbeck, Tex.; (c) March at Broken Arrow, Okla.; (d) individual a. m. observations at Broken Arrow, one for each month, showing characteristic velocity increase near the 500-meter level.

This nocturnal stratification is illustrated by a set of morning velocity curves at Broken Arrow, one curve for each month of the year (fig. 6, *d*). These curves show a rapid increase of 12 to 14 m. p. s. in velocity from the surface to the 500-meter level approximately; above this is a somewhat less rapid decrease to near the 2,000-meter level. This condition occurs at intervals throughout the year; it is infrequent in winter because the prevailingly strong winds aloft prevent the occurrence of the marked decrease in the upper part of the curves. In summer when the surface wind is from the south similar conditions may occur day after day.

None of these examples of wind stratification illustrates westerly winds over-running easterly surface winds; they are all taken from southerly component surface winds shifting as a rule into southwest or west at 2,000 meters. They occur with a great variety in the size, intensity, and position of the nothern low pressure area. Sometimes there is a small LOW in Kansas or Nebraska, or there may be a deep LOW along the northern border; but an invariable condition is the absence of strong latitudinal surface temperature gradients.

The effect of this stratification appears in the curves of mean velocity throughout the year. Figure 6, (*a*) and (*b*), show the mean a. m. and p. m. velocities for January and July, respectively, at Groesbeck; Figure 6, (*c*), shows the same data for March at Broken Arrow. The characteristic increase to the 500-meter level and a decrease above is seen in each morning curve. P. m. curves are practically straight to 2,000 meters in summer while a small increase occurs in winter. It will be noted that the daytime increase in surface velocities extends to somewhat less than 100 meters above the ground, while the flow of the main body of air below 2,000 meters is considerably retarded during the day, largely as a result of convection and the resulting friction along the land surface. The average diurnal change in velocity at Broken Arrow in March is 5 m. p. s. at 500 meters; on individual days it may amount to 15 m. p. s.

From kite observations it is found that nocturnal conditions begin to appear near sunset and increase in vigor until nearly midnight; steady motion then continues until convection sets in an hour or two after sunrise.

Wind stratification in the lower levels is important in kite work in the Southern States. Occasionally in winter the wind is too strong for good kite flying at the 500-meter level and it is advisable to wait until convection has caused the wind to moderate to some extent. In summer, on the other hand, this wind layer is the very foundation of successful kite flying. At this season most of the flights made at Broken Arrow and Groesbeck are obtained by floating out a line of kites on top of this wind layer. Then in reeling the wire in rapidly the kites are carried some distance aloft into the lighter wind. When this wind layer is absent in the morning, it is sometimes possible to get a flight at night. On account of the prevailingly light winds in summer, a considerable number of flights is made at these two stations at night after stratification and steady flow have begun.

*High winds.*—The percentage frequency of high winds for this region has not been studied in detail but the percentage for the year at Broken Arrow has been determined for the 500-meter level and is shown in Figure 7. This level, 1,650 feet, is near the usual height of the flights made by the air mail and therefore the altitude where high winds are most important. Using English units for this figure, the winds have been divided into classes of 30 m. p. h. or more, 40 m. p. h. or more, and 50 m. p. h. or more. A large majority of the winds in each class falls between south and southwest, the largest number being from the south-southwest. A secondary frequency in winter is from north and north-northwest but the number is small compared to the number from a southerly direction.

The annual percentage of observations in which the wind equals or exceeds 30 m. p. h. is 23; 40 m. p. h., 10; and 50 m. p. h., less than 2. As the greatest diurnal change in velocity occurs at this height, it is not surprising that 78 per cent of the winds exceeding 30 m. p. h. are observed in the morning. At the a. m. observation during the months November to April, inclusive, winds of

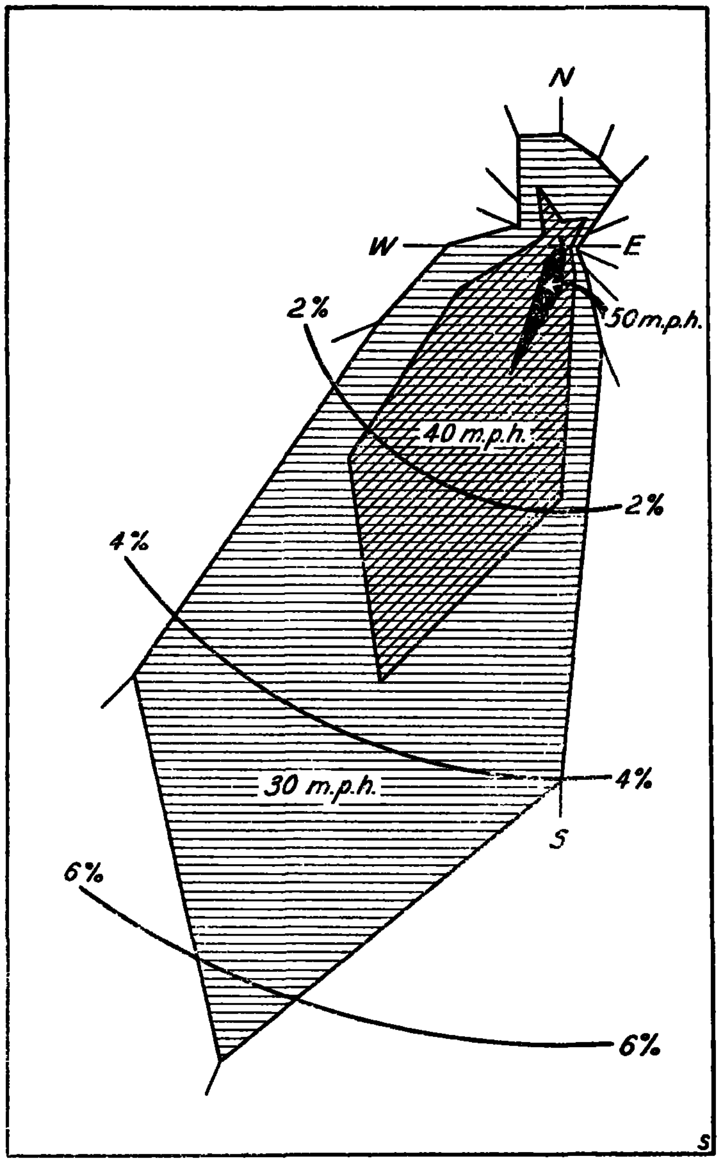


FIG. 7.—Percentage frequency of winds equalling or exceeding 30, 40, and 50 m. p. h. at 500 meters above Broken Arrow, Okla.

30 m. p. h. or more occur 44 per cent of the time; and from May to October, inclusive, 31 per cent. In the afternoon only 15 per cent equal or exceed 30 m. p. h. from November to April, and 7 per cent from May to October.

High wind records from kite observations have been published in *An Aerological Survey of the United States, Part I;* the percentage frequency of winds of 10 m. p. s. and over and 20 m. p. s. and over may be found in Table 20 of that publication; the highest winds observed are given in Table 21. Maximum winds in general are likely

[4] *The meteorological aspects of the thirteenth national balloon race, May 31, 1922.* By V. E. Jakl. MO. WEATHER REV. May, 1922. 50: 245–250.

to be somewhat higher on balloon records than on kite records for the reason that the kite flight usually follows the morning balloon observation and if a region of especially high winds is found it is likely to be avoided with the kites, or the kite flight delayed for a time.

While a knowledge of the distribution of high winds, as shown in Figure 7, will help in a general way to determine what may be expected in flying, much greater detail is desirable when applied to any particular route, as has been done by Mr. W. R. Gregg and Lieut. J. P. Van Zandt for the transcontinental air mail;[8] but such an analysis is beyond the scope of this paper. In individual cases the aviator who has a definite knowledge of existing winds gained from pilot balloon reports may often avoid strong head winds by flying above or below the customary height or by waiting until midday or later when this is possible.

*Winds at high altitudes.*—Winds at high altitudes are of very small importance to present day aviation; but during the last few years they have become a matter of considerable interest and speculation as affording a means of flying across the country at tremendous speed. For instance in the *Scientific American*, September, 1922, "Across America in Eight Hours," it is stated that the wind at 7½ miles up always blows from the west, "and maintains an average speed of something like 250 miles per hour."

Such statements are highly exaggerated. Pilot balloons have been sent up daily at a number of places over the United States during the past five years, and the highest velocities ever observed fall considerably short of the 250 miles per hour given as the average speed. During the winter, when the winds are strongest and blow almost continuously from a westerly direction, the average speed is about 100 to 115 miles per hour 6 miles above this region; while in summer the average speed drops to about 35 miles per hour over the southern part of the country; and winds from an easterly quarter occur with increasing frequency from the northern part of the country to the southern.

Both at Broken Arrow and Groesbeck 150 balloons have been followed to the 10-kilometer level (6.2 miles) during the 4-year period. The average speed for the year at that level at Broken Arrow is 74 miles per hour (33 m. p. s.) and at Groesbeck it is 66 miles per hour (29.4 m. p. s.). Twenty-five per cent of all winds observed at the 10-kilometer level at Broken Arrow have an easterly component, while 41 per cent at Groesbeck are easterly. In summer at Groesbeck the easterly component amounts to 66 per cent and the mean direction is northeast.

So it is not simply a matter of going up 6 or 7 miles any time and finding a gale from the west. The aviator who desires to make a record breaking trip by taking advantage of the strong winds aloft should, and generally does, consult the Weather Bureau to find out the odds in his favor.

[8] *The wind factor in flight: An analysis of one year's record of the Air Mail.* MO. WEATHER REV., March, 1923, 51: 111-125.

## UPPER AIR OBSERVATIONS AT SEA.

Because of the experimental work being carried on by the U. S. S. *Langley*, it has been impossible to make flights with the Aerograph as no planes or pilots have been available for this work.

On Thursday September 13, 1923, while the *Langley* was en route from Boston, Mass., to Norfolk, Va., and after flying exercises had been carried out, one Vought plane was assigned to make an aerological flight.

At this time the *Langley* was off the Virginia coast, and after the plane had been equipped with the Friez aerograph, the Schneider altigraph, and a Navy pocket altigraph, Lieut. Braxton Rhodes as pilot and Chief Quartermaster Williams as aerological observer, took off from the deck of the *Langley* and made an aerological flight to 15,000 feet.

In ascending to this altitude four separate layers of cloud forms were gone through. Nothing of importance concerning the weather was gained by this flight, the conditions being normal.

As before, it was found that the vibration was too great to expect accurate results from the Friez aerograph, although an entirely new method was used in attaching the instrument, but by experimenting during the flight it was learned that by making minor changes, the effect of vibration will be nearly or completely eliminated.

In the history of upper air observations this is the first time that an aerological flight has been made from the deck of a moving vessel at sea, and while the plane landed at the naval air station, Hampton Roads, Va., it is known, from past experiments, that it could have landed aboard the *Langley* just as it had taken off.

From this flight, then, it can be seen that in the near future, with the development of aircraft carriers, a regular schedule of upper air observations can be carried out while these vessels are at sea, and the results obtained used in compiling data heretofore not obtainable.—*Franklin G. Williams, C. Q. M., U. S. Navy.*

## THE ANTICYCLONE OF SEPTEMBER 12-18, 1923.

By ALFRED J. HENRY.

[Weather Bureau, Washington, D. C., October 17, 1923.]

In the previous number of this REVIEW[1] some comment was made upon the appearance of the first pronounced anticyclone of the season in the Canadian Northwest. In this number it is proposed to discuss in like manner the origin and movement of another larger and more enduring anticyclone that completely dominated the weather of eastern United States and Canada September 13-18, 1923.

In reality there were two anticyclones; the first is plotted as track No. VII and the second as track No. VIII of Chart I of this REVIEW. For convenience these will be referred to as the "first" and "second" anticyclone.

*The barometric situation.*—The barometric situation on the 10th was as follows: A trough of low pressure (29.9 inches) stretched from Minnesota south-southwest to Texas and an anticyclone (30.2 inches) covered the Lake region with a second anticyclone (30.2 inches) apparently moving southeastward from the Province of Alberta, attended by a sharp fall in temperature in western Saskatchewan and Assiniboia.

*Subsequent development.*—The Alberta anticyclone above mentioned advanced to eastern Montana in 24 hours and apparently continued to move in a southeasterly direction, although its identity after the 11th can not easily be distinguished.

On the morning of the 12th a fresh anticyclone (30.4 inches) appeared at Prince Albert, Saskatchewan, a sta-

[1] Henry, A. J.: The first cool wave of 1923 in the Dakotas and Lake region. MO. WEATHER REV., 51: p. 402.